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BIPED ROBOT DESIGNING AND INTERFACING

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ABSTRACT

The designing of a biped robot is the most challenging because of the inherent stability. However a walking robot has advantages over the wheeled robots. Although wheeled robots are commonly used, they only have limited ability to move to any destination. They suffer from the difficulties when travelling over uneven and rough terrains. In this work an attempt has been made to develop a prototype below hip a legged robot. The robot has 8 D o F in total that allow imitation of various human gaits. The conceptual design of the biped is done using Solid Works and the simulation is done by using M. Sc ADAMS

The prototype design is initially developed in Solid Works. The bipedal motion is simulated using M. Sc ADAMS software for mechanical system simulation. Aluminum is used for the fabrication. The robot uses 8 servo motors for actuating the various joints of the biped. The total weight of the biped is 1.15 kg and the motors are capable of delivering 1.6 Nm torque. The biped is interfaced with the controller of available Robix Rascal kit and by using the *Robix*^{R} software to move the biped.

KEYWORDS: Biped Robot, Degree of Freedom, Human Gaits, Solid Works, M.sc ADAMS, Robix Rascal Kit

INTRODUCTION

The research of humanoid robot is diverging into the various categories such as the artificial intelligence, robot hardware development, realization of biped locomotion and human-robot interaction. As these researches make progress many researchers have started to make their focus on the human friendly robots, which is partially inspired by the rapid growth of technology.

Bipedal robots will operate in a human environment with much greater efficiency than any other type of robot yet devised. It is hoped that eventually bipedal robots can be used to complete tasks which are too difficult or dangerous for humans. This includes applications such as working in extreme environmental conditions (such as in fire rescue operations), with toxic gases or chemicals, with explosives (such as land mines) or as an aide to humans in similar situations. Also, a useful by-product of research into bipedal robotics will be the enhancement of prosthetic devices. The state of research into bipedal robotics has progressed to the stage where dynamic walking gaits are being studied. Human beings usually employ a dynamic gait when walking as it is faster and more efficient than static walking.

Dynamic walking is characterized by a small period in the walking cycle where the center of gravity of the robot is not projected vertically onto the area of either foot. This requires there to be a period of controlled instability in the gait cycle, which is difficult to accomplish unless the mechanical system has been designed bearing this in mind

This thesis presents small scale low cost bipedal walking robot which can be used to investigate control and stability issues inherent in life sized robots. We examine in detail the issues surrounding the design of such a robot as well as the development of the control software.

METHODOLOGY

Mathematical Modeling

Kinematic analysis is performed using Denavit Hartenberg representation and the forward recursive equations to obtain the relation between angular displacement, velocity, and acceleration in terms of joint and link parameters. Further using Newton-Euler backward recursive equations for dynamic analysis the required torques at different joints are determined.

Kinematic Analysis

The kinematic analysis of the open chain system comprising position, velocity and acceleration analysis, of both translatory and rotary motion, can be divided into the following steps.

- Determine number of body parts and apply local coordinate system to each part.
- Determine the transformation matrix associated with each body part.
- Determine the position of each part in local coordinate system in local coordinates and global coordinates.
- Determine angular velocity of each body part.
- Determine angular acceleration of each body part.
- Determine the velocity of each body part.
- Determine the acceleration of each body part.

For the present biped motion only rotary joints have been considered.

Recursive Newton-Euler Formulation

By considering one leg the kinematic and dynamics analysis is done for the torque equations

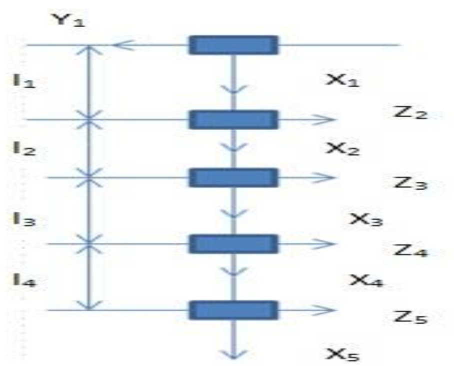

Figure 1: Kinematic Model

Table 1: D-H Matrix

Link	a_{i-1}	α_{i-1}	θ_i	d_i
1	0	0	0	0
2	l_1	90	θ_1	0
3	l_2	0	θ_2	0
4	l_3	0	θ_3	0
5	l_4	0	θ_4	0

Transformation Matrix

$$ {}^{0}_{5}T = {}^{0}_{1}T \cdot {}^{1}_{2}T \cdot {}^{2}_{3}T \cdot {}^{3}_{4}T \cdot {}^{4}_{5}T $$

$$ {}^{0}_{5}T = \begin{pmatrix} c_{1234} & -s_{1234} & 0 & l_4 c_{123} + l_3 c_{12} + l_2 c_1 + l_1 \\ 0 & 0 & 0 & 0 \\ s_{1234} & c_{1234} & 0 & l_4\ s_{123} + l_3 s_{12} + l_2 s_1 \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

Newton Euler Dynamics Formulation

We have derived all the equations for the links of the biped but in the below mentioned is for the 3rd link of the biped.

For i=3:

Angular Velocity

$$ {}^{4}\dot{v}_4 = \begin{pmatrix} l_3 c_3 (\dot{\theta}_1 + \dot{\theta}_3)^2 + l_3 s_3 (\ddot{\theta}_2 + \ddot{\theta}_3) - l_2 \dot{\theta}_1{}^2 c_1 c_{123} + l_2 \ddot{\theta}_2 s_{123} - l_1 \dot{\theta}_1{}^2 c_{23} + l_1 \ddot{\theta}_1 s_{123} - l_2 \dot{\theta}_2{}^2 c_{23} + l_3 c_{12} s_{12} s_3 \dot{\theta}_1{}^2 \\ -l_3 s_3 (\dot{\theta}_1 + \dot{\theta}_3)^2 + l_3 c_3 (\ddot{\theta}_2 + \ddot{\theta}_3) + l_2 \dot{\theta}_2{}^2 s_{23} + l_1 \ddot{\theta}_1 c_{123} + l_2 \ddot{\theta}_2 c_{23} + l_1 \ddot{\theta}_1 s_{123} + l_2 \dot{\theta}_2{}^2 c_1 s_{23} + l_3 c_1 s_{123} \dot{\theta}_1{}^2 \\ l_3 c_{12} \dot{\theta}_1 + (l_3 + l_3{}^2) s_{12} \dot{\theta}_1 (\dot{\theta}_2 + \dot{\theta}_3) - l_2 \dot{\theta}_1 (c_1 + s_1 \dot{\theta}_2) + l_2 s_1 \dot{\theta}_1 \dot{\theta}_2 - l_1 \dot{\theta}_1 - g \end{pmatrix} $$

Forces and Moment

$$ {}^{4}F_4 = m_4 \begin{pmatrix} -L_2 c_{123}^2 \dot{\theta}_1^2 - l_2 (\dot{\theta}_2 + \dot{\theta}_3 + \dot{\theta}_4)^2 + l_3 (\dot{\theta}_1 + \dot{\theta}_2)^2 c_3 + l_3 s_3 (\ddot{\theta}_3 + \ddot{\theta}_2)^2 - l_2 \dot{\theta}_1^2 c_1 c_{123} - l_2 \dot{\theta}_2 s_{23} + l_1 \ddot{\theta}_2 s_{23} \\ -l_1 c_{123} \dot{\theta}^2{}_1 + l_1 \ddot{\theta}_1 s_{123} - l_2 \dot{\theta}_2{}^2 c_{23} + l_3 c_{12} s_{12} s_3 \dot{\theta}_1{}^2 \\ \\ -L_2 c_{123} s_{123} \dot{\theta}_1^2 - l_3 (\ddot{\theta}_2 + \ddot{\theta}_3 + \ddot{\theta}_4)^2 s_3 - l_3 (\dot{\theta}_1 + \dot{\theta}_2)^2 s_3 + l_3 c_3 (\ddot{\theta}_3 + \ddot{\theta}_2)^2 + l_2 \dot{\theta}_1^2 s_{123} + l_1 \ddot{\theta}_1 s_{123} + \\ + l_1 \ddot{\theta}_1 c_{123} + l_2 c_{23} \dot{\theta}^2{}_2 + l_1 \dot{\theta}_1{}^2 c_1 s_{123} + l_2 \dot{\theta}_2 c_{23} + l_3 c_{12} s_{12} c_3 \dot{\theta}_1{}^2 \\ \\ -L_3 c_{123} \dot{\theta}_1 + l_3 c_{12} \dot{\theta}_1 + (l_3 + l_3{}^2) s_{12} \dot{\theta}_1 (\dot{\theta}_2 + \dot{\theta}_3) - l_2 \dot{\theta}_2 (c_1 s_1 + \dot{\theta}_2) + l_2 s_1 \dot{\theta}_1 \dot{\theta}_2 - l_1 \dot{\theta}_1 - g \end{pmatrix} $$

$$ {}^{4}N_4 = $$

$$ \begin{pmatrix} [m_4 (s_{123} \dot{\theta}_1 + c_{123} (\dot{\theta}_1 + \theta_2 + \dot{\theta}_3))(h^2{}_4 + l^2{}_4)]/12 + [m_4 (l_4^2 - h_4^2) c_{123} \dot{\theta}_1 (\dot{\theta}_2 + \dot{\theta}_3 + \dot{\theta}_4)]/12 \\ [m_4 (c_{123} \dot{\theta}_1 + s_{123} (\dot{\theta}_1 + \theta_2 + \dot{\theta}_3))(h^2{}_4 + w^2{}_4)]/12 + [-m_4 (w_4^2 - h_4^2) s_{123} \dot{\theta}_1 (\dot{\theta}_2 + \dot{\theta}_3 + \dot{\theta}_4)]/12 \\ [m_4 (\ddot{\theta}_2 + \ddot{\theta}_3 + \ddot{\theta}_4)(l^2{}_4 + \omega^2{}_4)]/12 + [(m_4 \dot{\theta}_1^2 s_{123} \dot{\theta}_1 (\omega_4^2 - l_3^2))]/12 \end{pmatrix} $$

Inward Iteration

Forces acting on each link:

$$ {}^{i}f_i = {}^{i}_{i+1}R \cdot {}^{i+1}f_{i+1} + {}^{i}F_i $$

For link i=4:

$$ {}^{4}f_4 = {}^{4i}_{5}R \cdot {}^{5}f_5 + {}^{4}F_4 $$

$$= {}^{4}_{5}R \cdot \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} + {}^{4}F_4$$

From above we get,

$${}^{4}f_4 = {}^{4}F_4$$

We know, ${}^{4}f_4 = {}^{4}F_4$

Moment for each Link

$${}^{i}n_i = {}^{i}N_i + {}^{i}_{i+1}R \cdot {}^{i+1}n_{i+1} + {}^{i}p_{c_i} \cdot {}^{i}F_i + {}^{i}p_{i+1} X \, {}^{i}_{i+1}R \cdot {}^{i+1}F_{i+1}$$

For link i=4,

$${}^{4}n_4 \;\; = {}^{4}N_4 + {}^{4}p_{c4} \cdot {}^{4}F_4$$

$$T_i = {}^{i}n_i^{\,T} \cdot {}^{i}\hat{Z}_i$$

By extracting the Z-Terms we get, the torque equation.

$$T_4 = m_4\{[l_4^2 + w_4^2][\ddot{\theta}_2 + \ddot{\theta}_3 + \ddot{\theta}_4] + s_{123}c_{123}\ddot{\theta}_1[w_4^2 - l_4^2]\} + L_3[\ddot{\theta}_2 + \ddot{\theta}_3 + \ddot{\theta}_4] - L_2 s_{123}c_{123}\dot{\theta}_1^{\,2} - l_3 s_3[\dot{\theta}_2 + \dot{\theta}_3]^2$$

$$+ l_3 c_3[\ddot{\theta}_2 + \ddot{\theta}_3] + l_2 s_2\dot{\theta}_2 + l_1 s_{123}\dot{\theta}_1^{\,2} + l_1 c_{123}\ddot{\theta}_1 + l_2 c_{23}\ddot{\theta}_2 + l_3 s_{12}c_{12}c_3\dot{\theta}_1^{\,2} + l_2 s_{123}c_{123}\dot{\theta}_1^{\,2}$$

From the equation we had obtained torque at the joint 4 similarly all the torques of joints are calculated.

Developing a CAD Design

The design is developed in the Solid Works according to the required dimensions .Solid Works has high end features which can directly give the weight and centre of gravity of the object. Initially all the parts are developed in the solid work and assembled together by using the Assembly option.

Table 2: Degrees of Freedom

S. No	Part Name	No. of DoF
1	Hip	2 D o F X 2 = 4 DoF
2	Knee	1 D o F X 2 = 2 DoF
3	Ankle	1 D o F X 2 = 2 DoF
		Total 8 DoF

Specifications of the Biped

- Weight is 1.15 Kg
- Height is 330 mm and 270 mm.
- Material used is Aluminum.
- Motors used are 1.6Nmm.

- Software used is Robix Rascal software.
- Degrees of Freedom are 8

Table 3: Links Length

Link	Length (mm)
Link 1	74
Link 2	118
Link 3	118
Link 4	30

Solidwork Modelling

The figure shows the 3-D model developed in Solid Works. Solid Works is an excellent modeling tool which provides us with tremendous features and flexibility in 3-D modeling. It allows us to specify material of the various parts. We can choose the material o four choices. The properties of various materials are stored in it. Thus, we can calculate exact weight of the model before actually fabricating it. In addition to that, w e can also locate the Center of Gravity of the system. We can also assign mathematical relations between two o surfaces, objects etc. For example if a shaft is concentric with a bearing we can define relation such that the e shaft can move inside the bearing but can't move out of it. This method of assigning relations is called Mating. By using the solid works we can obtain directly the weight of the component and the weight of the entire biped, also we can get the moment of inertia, centre of mass etc.

COM of a Biped in Different Position

Output Coordinate System

The center of mass and the moments of inertia are output in the coordinate system of Assem3

Mass properties of Assem3 (Assembly Configuration - Default)

Output coordinate System:

Mass = 1150grams

Volume = 344732.10 cubic millimeters

Surface area = 255838.00 millimeters^2

Center of mass: (millimeters)

X = -6.66;Y = -148.29;Z = 22.87

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0.02, 1.00, -0.05) Px = 1226195.97

Iy = (-1.00, 0.02, 0.08) Py = 4131406.14

Iz = (0.08, 0.05, 1.00) Pz = 4968366.32

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 4135191.99 Lxy = 58352.36 Lxz = -68017.93

Lyx = 58352.36 Lyy = 1236404.48 Lyz = -182159.16

Lzx = -68017.93 Lzy = -182159.16 Lzz = 4954371.96

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 15445384.02 Ixy = 554783.71 Ixz = -144569.34

Iyx = 554783.71 Iyy = 1521407.21 Iyz = -1885720.93

Izx = -144569.34 Izy = -1885720.93 Izz = 16024176.63

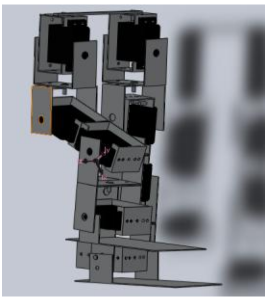

Figure 2: COM of the Biped

Simulation of Biped

Analysis of the Developed Biped

Adams is the most widely used multi body dynamics and motion analysis software in the world. Adams helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

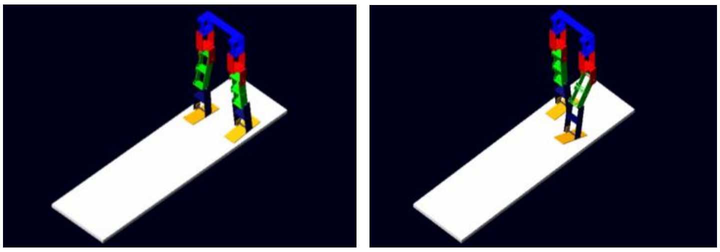

Figure 3: Adams Simulation

By using Adams the movement of the biped can be known and the walking movement of the biped is also analysed,which is require for us. During the simulations, ADAMS/View provides the ability to animate the models movement and view key physical measures of specific simulation data.

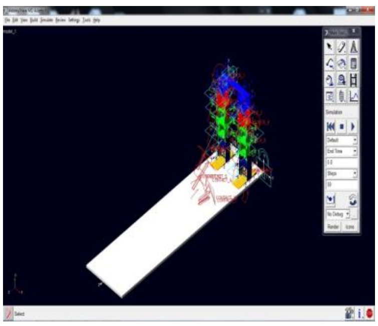

Figure 4: Biped with the Assigned Forces

In Adams View all the joints are connected by using the revolute joints.A ground is designed and locked.The contact forces are assigned between the foot and the ground.So that when one leg move the reaction forces and the torques at the other foot developed are used to make the biped in a stable position.

Adams Model and Verification

Model verified successfully

VERIFY MODEL: .model_1

8 Gruebler Count (approximate degrees of freedom)

10 Moving Parts (not including ground)

8 Revolute Joints

1 Fixed Joints

8 Degrees of Freedom for .model_1

There are no redundant constraint equations.Model verified successfully

Developing a Prototype and Interfacing to Controller

The biped is composed of two legs. The joints are located at hip, knee and ankle. This robot consists of 8 actuators. The biped is made of aluminum material which has 8 D o F. According to the design made in the solid works with the required dimensions. Aluminum is used for the prototype model.

Figure 5: Front View of the Biped Figure 6: Robix Controller

The metal is cut into required sizes and the drilling is done to join the different links of the leg. The dimensions of each leg are taken according to the humans. Each bracket is developed with a dimension of 57mmX30mmX50mm and screwed together to make as a link .The foot is designed 130mmX70mmX1mm which gives the stability to the biped while walking and also to maintain the stability in the static position. Both the legs are joined by using a wooden block. The entire height of the biped is 33cm and width is 20cm.

Different Stances of a Biped

The prototype was developed and moved different links by using the Robix Rascal software.

Figure 7: Different Stances of the Biped

RESULTS AND DISCUSSIONS

The mathematical modeling of Kinematic and Dynamic analysis of the Biped was derived by considering 4 D o F for each leg, using the Newton's Euler formulation were torques are obtained. The final design was modeled using the Solid Works according to the designed dimensions. The M. Sc ADAMS is used for the dynamic simulation of the biped to know the movements and the walking pattern at which different links are moved.

The graphs were obtained from the M. Sc ADAMS after the dynamic simulation of the biped. The contact forces are given in between the foot and the ground

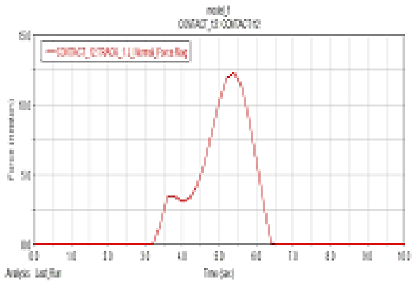

Figure 8: Reaction Force between Left Foot and Ground

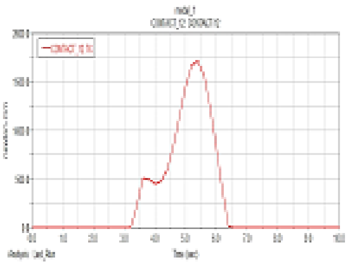

Figure 9: Reaction Torques between Left Foot and Ground

From the graphs we can see the both reaction forces and torques are obtained to make biped in stable. When left leg is in contact with the ground and the right leg is in air to take a step the force obtained is 12N and the reaction torque is 1.7Nm which are required to make the biped in the stable position in dynamic simulation

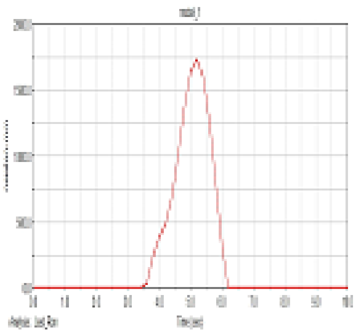

Figure 10: Reaction Force between Right Foot and Ground

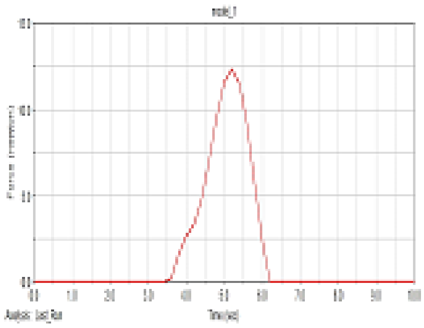

Figure 11: Reaction Torques between Right Foot and Ground

The above graphs are developed at the contact between the right foot and the ground when the left leg is in air for the next step. The force developed at the right foot is 12.5N and the torque obtained is 1.7Nm which are required.

From the graphs we had chosen 1.6Nm torque DC Servo motor.

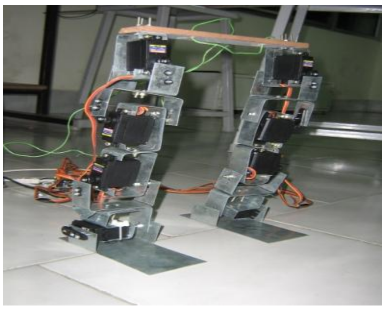

Figure 12: Developed Biped

The Biped prototype is developed by using the 1.6Nm Servo motors. It had imitated the human gaits but the problem of stability has raised because of the variation of centre of mass of the system.

CONCLUSIONS

The work represents the development of a bipedal robot. The robot has features of small size and light weight. The light weight property could help to achieve a faster speed at walk. It has 8 D o F to imitate the human gaits and the dimensions of the biped are assumed according to the human dimensions. The use of simple kinematics techniques used towards the design of biped. The design is made by using solid works and the simulation is done in M. Sc Adams, to know the assumed parameters and the design constraints. A variety of commercial software intended to facilitate learning the Robix rascal and Adams software. In the final stage the Biped prototype is developed and the imitated the different human gaits.

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APPENDICES

D o F – Degree of Freedom